

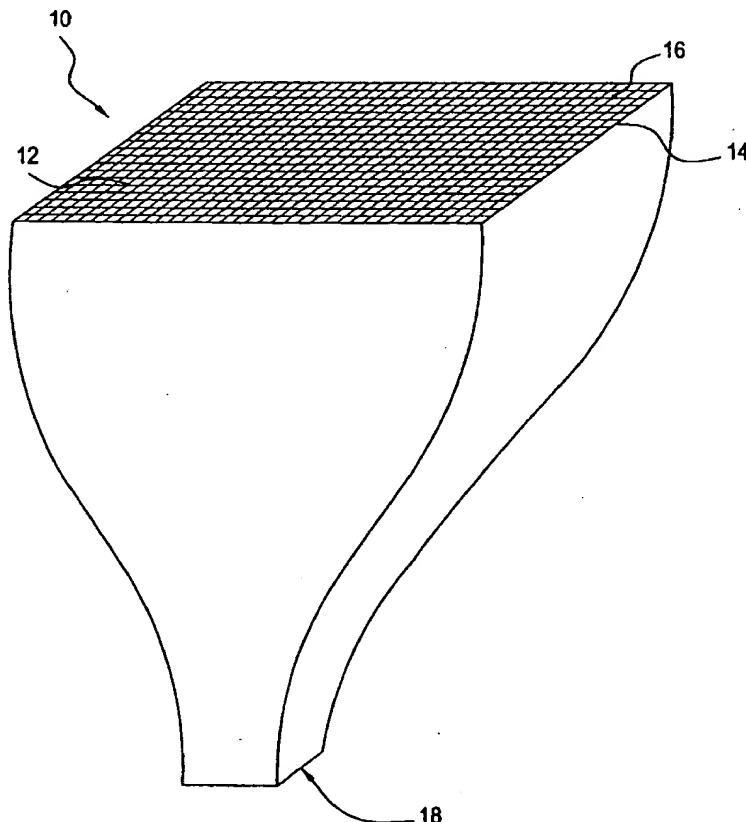
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**(54) Title:** REDRAWN CAPILLARY IMAGING RESERVOIR**(57) Abstract**

Method and apparatus for transferring fluids, especially for use in biological testing, includes an array of capillaries (10) having an inlet end (16) and an outlet end (18) which is smaller than the inlet end (16). The capillary array can be formed by extruding and redrawing a honeycomb pattern of channels. Arrays of different specific binding partners formed using the capillary array are also described.



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## REDRAWN CAPILLARY IMAGING RESERVOIR

This application claims the benefit of European Application number 98401021.5 filed on 4/27/98 and Provisional Application number 60/091707 filed on 7/3/98.

### Field Of Invention

The invention relates to a device and method for the printing of high density arrays for use in biological and chemical assays as well as a device that can be used in sample transfer between multiwell plates of differing well density.

### Background of Invention

Hybridization is a hydrogen- bonding interaction between two nucleic acid strands that obey the Watson-Crick complementary rules. All other base pairs are mismatches that destabilize hybrids. Since a single mismatch decreases the melting temperature of a hybrid by up to 10° C, conditions can be found in which only perfect hybrids can survive. Hybridization comprises contacting the strands, one of which is usually immobilized on a solid support and the other usually bears a radioactive, chemiluminescent or fluorescent label, and then separating the resulting hybrids from the unreacted labeled strands by washing the support. Hybrids are recognized by detecting the label bound to the surface of the support.

Oligonucleotide hybridization is widely used to determine the presence in a nucleic acid of a sequence that is complimentary to the oligonucleotide probe. In many cases, this provides a simple, fast, and inexpensive alternative to conventional sequencing methods. Hybridization does not require nucleic acid

cloning and purification, carrying out base-specific reactions, or tedious electrophoretic separations. Hybridization of oligonucleotide probes has been successfully used for various purposes, such as analysis of genetic polymorphisms, diagnosis of genetic diseases, cancer diagnostics, detection of viral and microbial pathogens, screening of clones, genome mapping and ordering of fragment libraries.

An oligonucleotide array is comprised of a number of individual oligonucleotide species tethered to the surface of a solid support in a regular pattern, each species in a different area, so that the location of each oligonucleotide is known. An array can contain a chosen collection of oligonucleotides, e.g., probes specific for all known clinically important pathogens or specific for all known clinically important pathogens or specific for all known sequence markers of genetic diseases. Such an array can satisfy the needs of a diagnostic laboratory. Alternatively, an array can contain all possible oligonucleotides of a given length  $n$ . Hybridization of a nucleic acid with such a comprehensive array results in a list of all its constituent  $n$ -mers, which can be used for unambiguous gene identification (e.g., in forensic studies), for determination of unknown gene variants and mutations (including the sequencing of related genomes once the sequence of one of them is known), for overlapping clones, and for checking sequences determined by conventional methods. Finally, surveying the  $n$ -mers by hybridization to a comprehensive array can provide sufficient information to determine the sequence of a totally unknown nucleic acid.

Oligonucleotide arrays can be prepared by synthesizing all the oligonucleotides, in parallel, directly on the support, employing the methods of solid-phase chemical synthesis in combination with site-directing masks as described in US Pat. 5,510,270. Four masks with non-overlapping windows and four coupling reactions are required to increase the length of tethered oligonucleotides by one. In each subsequent round of synthesis, a different set of four masks is used, and this determines the unique sequence of the oligonucleotides synthesized in each particular area. Using an efficient

photolithographic technique, miniature arrays containing as many as  $10^5$  individual oligonucleotides per  $\text{cm}^2$  of area have been demonstrated.

Another technique for creating oligonucleotide arrays involves precise drop deposition using a piezoelectric pump as described in US Pat. 5,474,796. The piezoelectric pump delivers minute volumes of liquid to a substrate surface. The pump design is very similar to the pumps used in ink jet printing. This picopump is capable of delivering 50 micron diameter (65 picoliter) droplets at up to 3000 Hz and can accurately hit a 250 micron target. The pump unit is assembled with five nozzles array heads, one for each of the four nucleotides and a fifth for delivering activating agent for coupling. The pump unit remains stationary while droplets are fired downward at a moving array plate. When energized, a microdroplet is ejected from the pump and deposited on the array plate at a functionalized binding site. Different oligonucleotides are synthesized at each individual binding site based on the microdrop deposition sequence.

Another approach using arrays is the pin dipping method for parallel oligonucleotide synthesis. Geysen, *J. Org. Chem.* 56, 6659 (1991). In this method, small amounts of solid support are fused to arrays of solenoid controlled polypropylene pins, which are sequentially dipped into trays of the appropriate reagents. The density of the arrays is limited by this process.

Further approaches to forming an array involve taking presynthesized oligonucleotide or cDNA sequences from separately prepared aqueous mixtures and transferring them to substrate either individually or in some small multiple. This may be accomplished for example by repeatedly contacting a substrate surface with typographic pins holding droplets, using ink jet printing mechanisms to lay down an array matrix, or by use of a pen plotter. These printing processes are limited by the time and expense required in transferring  $10^3$  or greater different sequence mixtures onto defined positions on a substrate.

### Summary of Invention

The present invention provides a capillary reservoir device and liquid deposition tool and methods for depositing a high density biological or chemical array onto a substrate. The tool is made up of a plurality of open ended channels

collectively forming a matrix. The matrix has been redrawn and cut such that the pitch of the channels on the loading end is far larger than the pitch of the channels on the liquid delivery end. The upper portion of each channel serves as a reservoir, while the opposing end, which has been formed by the redrawing process, is diametrically sized such that liquid in the reservoir is retained by capillary pressure at the delivery end. At any point along the height of the capillary reservoir device, all cross-sectional dimensions and areas are uniformly reduced. In other words, the on-center orientation of any two channels, also referred to as the pitch between 2 channels, measured as a function of the diameter of any cross section, is constant throughout the structure. In another embodiment, a variation of the device of the present invention may be used in transferring sample between multiwell plates of different well density.

#### **Brief Description of the Figures**

FIG. 1 is a three dimensional view of the device of the present invention.

FIG. 2 depicts a plurality of connected capillary tubes prior to redraw.

FIG. 3 is an illustration of the output end of the device being dipped into a liquid reservoir in order to impart wettable characteristics to the interior of the channels.

FIG. 4 is an illustration of the output end of the device being trimmed in order to expose a non wetting surface.

FIG. 5 is a three dimensional view of a preform block of material that is being extruded through a honeycomb die.

FIG. 6 is a three dimensional view of an extruded block that has been subsequently redrawn.

FIG. 7 is a side view of an extruded block that has been subsequently redrawn and is being subjected to a curing process.

FIG. 8 is a three dimensional view of a series of blocks that have been cut from the redrawn portion of the device of FIG. 7.

FIG. 9 is a three dimensional view of a block of FIG. 8 being sliced by a blade.

FIG. 10 is a three dimensional view of three high density array plates of the present invention.

FIG. 11 is an exploded view of a method of transfer of liquid sample from a multiwell plate to the capillary reservoir device of the present invention.

5 FIG. 12 is a three dimensional view of the device of FIG. 11 as used to deposit liquid sample to a receiving plate.

FIG. 13 is a cross sectional view of a capillary reservoir device of the present invention engaged by sealing means on both ends.

10 FIG. 14 is a cross sectional view of one channel of an embodiment of the capillary reservoir device of the present invention.

FIG. 15 is a three dimensional view of a printing machine employing the capillary reservoir device of the present invention.

FIG. 16 is a partial cross sectional view of the pin plate of FIG. 15 contacting the output end of the capillary reservoir device.

15 FIG. 17 is a partial cross sectional view of the pin plate of FIG 16 after removal from the output end of the capillary reservoir device.

FIG. 18 is a partial cross sectional view of the pin plate of FIGS. 15-17 after deposition of liquid material onto a substrate.

20 FIG. 19 is a cross sectional view of a printing tool of the present invention.

FIG. 20 is a cross sectional view of another embodiment of a printing tool of the present invention.

FIG. 21 is a cross sectional view of another embodiment of a printing tool of the present invention.

25 FIG. 22 is a partial cross sectional view of a slab of material which when assembled with other like slabs forms a preform.

FIG. 23 is a partial cross sectional view of a plurality of slabs piled one upon another and prior to fusion.

30 FIG. 24 is a partial cross sectional view of a preform formed by fusing the slabs of FIG. 23.

## Detailed Description of the Invention

### 5 Printing Tool

Glass and organic polymer redraw processes are well known and have been used to form precision tubing, sheets and fiber bundles with complex cross sections. The present invention adapts the known redraw technique in a unique way to form a container having an array of channels that can individually deliver  
10 small volumes of liquid either onto a substrate, to a typographic pinplate, or into wells of a multiwell plate. The term "redraw" is a term of art in the optical fiber community meaning the reduction in diameter of a preform. For purposes of this application, the term shall be synonymous with other known terms of art including "draw-down" and "draw".

15 The redraw technique is instituted on a multi-celled extruded block, also referred to as a honeycomb substrate, or a collection of connected capillary tubes. An important aspect of the redraw technique is that relatively large glass or polymer structures having complex cross-sectional configurations, corresponding to complex cross-sectional configurations of the final product, may be easily  
20 formed to desired dimensions. During the redrawing or stretching process, all cross-sectional dimensions and areas are uniformly reduced while the present tolerance remains constant. Thus, for purposes of illustration, a 1 inch dimension having a tolerance of 1% e.g.,  $\pm 0.01$  inch, in a 10 to 1 reduction results in a 0.1 inch dimension and a tolerance of  $\pm 0.001$  inch. A further 10 to 1 reduction  
25 results in a 0.01 inch dimension and a tolerance of  $\pm 0.0001$  inch.

In order to form a capillary reservoir device from glass, glass ceramic, or ceramic material, one must use a thermoplastic binder such as paraffin wax or a binder as described in US Patent 5,602,197, incorporated herein by reference, and combine it with an inorganic powdered material, preferably PYREX 7761 sold by  
30 Corning Incorporated powder with frit size centered on 10  $\mu\text{m}$ . This organic/inorganic mixture is then extruded through a counter rotating twin screw extruder. operated at room temperature. A die determines the dimensions of the



extruded material. Preferably, a 2-7 inch diameter, square or round channeled, monolithic honeycomb preform with 25-15 mil channel walls and 200-400 cells per square inch of frontal area results from the extrusion. The preform may be extruded in either round, rectangular or square cross sectional shape. The cross sectional shape of the cells may be any shape as determined by the die. The organic binder must be carefully removed by heating slowly to a sufficient temperature to cause volatilization and pyrolysis of the organic binder. Slump and other distortion is avoided by careful selection and control of the rheology, inorganic volume loading, and binder pyrolytic/volatilization characteristics. After binder removal, the preform of packed particulates is then sintered to meld the powder particles, while keeping the shape. In order to control wall sagging, sintering conditions must be closely monitored. The preform is preferably sintered vertically in order to avoid distortion. Sintering condition for PYREX 7761 is approximately 675° C for 1 hour. At this temperature, glass particle binding occurs and 10-15% shrinkage uniformly occurs throughout the structure. What remains is a glass, glass ceramic, or ceramic depending on the sintering schedule and the composition of the original powder material. For use with this invention, preferably the firing schedule and powder composition should be modified in such a way as to create substantially identical channel walls of high density and no open porosity. The resulting honeycomb block has a plurality of parallel channels or cells extending therethrough. The block may be any length as determined by the point at which it is cut from the extruder.

#### **Example- Extrusion and Sintering**

Table 1 shows the composition of PYREX 7761 glass. The inorganic powder is made from PYREX 7761 cullet: crushed, magnetically separated, ball milled (alumina), and ultrasonically screened (-325 mesh).

**Table 1**

Compound	Weight Percent (%)
SiO <sub>2</sub>	78.92
K <sub>2</sub> O	2.76

B <sub>2</sub> O <sub>3</sub>	18.27
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Table 2 shows the batch composition of the extrudable mixture.

**Table 2**

Ingredients	Weight (grams)
PYREX 7761 powder	7938
Oleic Acid	80
Dow F-40M METHOCEL	558
Water (DI)	1985

The inorganic powder, the METHOCEL, and the Oleic Acid are blended together in a LITTLEFORD mixer, and then mulled together with the water addition in a LANCASTER mixer. The mix is then further mixed by evacuation and spaghetti extrusion (3 times). Finally, the batch is extruded through a die to be formed into a multi-celled preform which is cut from the extrudate, ready for sintering.

Table 3 shows the furnace schedule used to sinter the preforms. The preforms are vertically suspended during sintering to minimize bowing.

**Table 3**

Furnace Schedule
1) Room Temperature to 300°C at 50°C/hr.
2) 300°C to 550°C at 20°/hr.
3) 550°C to 700°C at 50°C/hr.
4) Hold at 700°C for 2 hours.
5) 700°C to Room Temperature (power off).

Once the preform is sintered, the resulting structure is heated and undergoes a redraw reduction. Redraw takes place approximately at approximately 20° C to 100° C above the glass transformation temperature. For

PYREX 7761, the sintered block is reheated to 870° C over approximately 1.5 hours, in order to reach a +/- 20° C temperature uniformity within the section of the block to be stretched. The redraw process occurs in two steps; first, the block is arranged such that the channels are aligned vertically; and, a portion of the extruded block is restrained, while the weight of the structure is allowed to pull the unrestrained portion downward. Second, a constant force is applied to the unrestrained portion to further facilitate the draw. Once the extruded block is stretched to a predetermined diameter, depending on the cross sectional size requirement for the output end of the device, the process is stopped by temperature reduction. This annealing step preferably occurs over one hour in which the temperature is dropped to 20°C. As an example, for a 180 mm long cylindrical block having a 22 mm cross sectional diameter to be drawn to a cross sectional diameter of 4.2 mm, the block must be drawn approximately 920 mm in length. It is preferred that, after redrawing, the length of the capillary reservoir device be between 2 and 3 times the diameter of the block prior to redraw, in order to optimize the liquid retaining capillary characteristics of the individual channels.

In producing a bent reservoir device, as required in some embodiments, the drawn piece is maintained at a temperature of approximately 850° C in the portion to be bent. The piece is removed from the oven and bent at the appropriate angle, 180° for example. After bending, the piece is placed in an annealing oven in order to cool to room temperature without thermal stress.

After annealing to approximately 20° C over the course of approximately 1 hour, the piece whether bent or not, is cut on the reduced section of the block, which becomes the output end of the reservoir device, and may also be cut on the loading or input end by a diamond saw for example. The cutting is preferably performed under internal water flux in order to prevent any glass chips or fragments from lodging in the channels. The output end of the piece can then be finished by successively polishing with 12 µm, 3 µm, 1 µm, and 0.3 µm grit polishing paper. If the device is to be used in printing extremely low volume liquid drops, it is important to achieve a flatness of approximately  $\pm 2$  µm across

the output end of the device. The device may be further finished under fire polish at approximately 450° C for one hour.

Optionally, when using a binder such as those disclosed in U.S. Pat. 5,602,197, the option exists to redraw the preform after extrusion, but prior to binder removal and sintering. Redraw in this case is done as it would be for a thermoplastic polymer; in that the preform, or the section of the preform to be redrawn, is reheated to a softened or partially melted state whereupon the preform is redrawn by stretching. An advantage of using this technique is that inorganic particulates can be used that cannot be redrawn in the inorganic state, such as zirconia, alumina, etc.

In an embodiment in which a capillary reservoir device is made from a thermoplastic polymer, the polymer is initially extruded through a twin screw extruder and die operating at the melting temperature of the thermoplastic material, for example, polypropylene is extruded at approximately 180° C. The target cell density and wall thickness is substantially the same as the glass embodiment discussed above. Once the block has been extruded, the polymer redraw is performed as above and may require external heating of the structure, or the section to be redrawn, to 150°C, for example in polypropylene. The redraw may also require internal heating of the polymer structure by means of forced heated air, for example, in order to preclude any internal temperature gradient within the structure during redraw. Although the extrusion has been demonstrated with a polyolefin, specifically, polypropylene, it should be understood that any thermoplastic polymer, as recognized by one skilled in the art, may be used for this process.

Although a cylindrical extrusion is easier to perform in both powdered glass and plastic, a square or rectangular extrusion is preferred in order create a tool capable of depositing a rectilinear array.

Both extrusion of the polymer and the powdered glass is ideally performed by a vertical extrusion process. Vertical extrusion helps reduce problems of wall sagging due to gravitational effects. However, a horizontal extrusion process may be preferred in a mass production setting.

Yet another option for drawing down an extruded cellular body is to fill in the open cells of an extruded preform with a molten wax that exhibits similar plastic properties to the wet batch when solidified. The cooled body, consisting of the wet extruded cellular preform and the solidified plastic wax in the cells, is then pushed through a size reducing die at room temperature. By partially pushing the composite body through a die, a body with the desired transition from large to small cells may be obtained. Afterwards, the wax is melted and removed; then the cellular body is dried, fired and finished in the normal manner. A suitable wax for this technique is a microcrystalline hydrocarbon wax with a high needle penetration hardness (15+). This alternative drawdown technique is more fully disclosed in commonly assigned U.S. Patent Application 60/068,230, incorporated herein by reference.

FIG. 1 shows a capillary reservoir device 10 that is the subject of the present invention. In a preferred embodiment, the device ideally comprises a matrix of square channels 12, 100 channels along each outer wall 14 of the structure and 10,000 in total. The top of the device is the fluid loading or input end 16 of the device. The exposed face of the input end shall be called the input face. Each side of the input end 16 of the device is approximately 112.5 mm. The surface area of the entire input face, in this embodiment, is approximately 12,656 mm<sup>2</sup>. The structure has been redrawn such that the length of each side on the output end 18 of the matrix is approximately 22 mm. The exposed face of the output end shall be called the output face. The surface area of the output face is approximately 484 mm<sup>2</sup>. Each channel 12 within the device 10 is self contained and decreases in cross sectional area in approximate proportion to the decrease in total cross sectional surface area. Thereby, a channel having a width or pitch of 1.125 mm at the top surface, as in FIG. 1, has a width or pitch of approximately 0.22 mm at the bottom surface. The surface area of a cross-section of one individual channel as a proportion of the cross sectional area of a perpendicular plane taken at any point along the height of the vertical standing device is approximately constant. Wall thickness may increase slightly as a proportion of the total cross sectional area as the device is redrawn, but the number of channels is constant as well as the relative position of each channel in the matrix as defined

by the on-center channel to channel pitch. Put another way, the device has a plurality of open ended channels extending from an input face to an output face wherein at least along a predetermined length, each channel decreases equally in diameter, cross sectional area, and wall thickness.

5 Another alternative for making a capillary reservoir device is to etch or press channels in a surface of a plurality of slabs, pile the slabs one upon another forming a block having a plurality of channels formed therethrough, fusing the slabs, and redrawing the entire structure. Creating a preform by this method is shown in FIGS. 22 and 23. FIG. 22 shows a cross-sectional view of a portion of a  
10 slab 130. The slab 130 has a plurality of evenly spaced parallel channels 132 formed into a top surface 134. The channels can be made by any of a variety of known methods. If the material is glass, the channels may be etched, pressed, or created by precision rolling. If the material is a polymer, the slab may be formed by injection molding techniques, for example. FIG. 23 shows a partial cross  
15 sectional view of a plurality of slabs 130 piled one on another. The bottom surface 136 of each slab 130 serves to close the channels 132 of the slab immediately beneath it. A top piece 138 without channels seals the channels of the topmost slab. The entire construct is then heated to a temperature such that the slabs fuse together thereby creating a block 140 capable of being redrawn as  
20 shown in FIG. 24. Blocks having any number of channels having any size diameter or shape may be formed using this technique.

Virtually any block made from a thermoplastic material having a plurality of parallel channels formed therethrough may be redrawn in order to form the device of the present invention.

25 It should be noted that an alternative method for making a capillary reservoir device is to bind together a plurality of individual tubes or capillaries. The tubes may be bound together into a bundle having any number of tubes. The bundle is then redrawn and finished in the same fashion as an extruded and redrawn block. FIG. 2 shows the output end 20 of such a bundle of capillary  
30 tubes 22 after redraw. The tubes 22 serve the same function as the channels 12 of the device of FIG. 1. But for specific references to figures, the terms channel and tube are analogous hereinafter while describing the device.

As an example to demonstrate feasibility, 22 tubes 22 were bonded together in rows of 7, 8 and 7 tubes. The matrix of 9 mm tubes was then redrawn such that tube to tube center spacing became 350  $\mu\text{m}$ , and the diameter of the capillary output opening in each tube was 180  $\mu\text{m}$ .

5 The planar cut that exposes the output face of the device of either FIG. 1 or FIG. 2, is preferably non-wetting. For example, in FIG. 2, the tube interior 24 preferably has a wetting surface, while the tube ends 26 are preferably non-wetting. Similarly, the interior walls of the channels 12 of the device of FIG. 1 are wetting, while the wall ends are non-wetting. Because of the wetting channel  
10 interior and non-wetting end of each channel, droplets of liquid tend to bead on the end of each channel. Further, the non-wetting surface of the entire output plane of the device prevents crosstalk between channels at the output end.

Whether the device is made from a redraw of an extruded block or assembled block, or from bonded capillary tubes, the wetting characteristics of  
15 the output face may be obtained in the same way. To obtain the wettability characteristics of the output face in a device made of a material that is only moderately wetting, such as polystyrene is to water, or non-wetting such as polyolefins such as polyethylene and polypropylene are to water, wettability can be improved with oxidizing treatments. For example, oxidizing chemical  
20 etchants such as sulfuric or chromic acids may be introduced to the channel interiors. One way of subjecting the channel interiors to the oxidizing etchant, or any other liquid that will coat the interior channel walls is illustrated in FIGS. 3-5. FIG. 3 illustrates how liquid 28 from a reservoir 30 coats the interior 24 of the tubes 22 on the output end 20 of the device of FIG. 2. The device is next sliced in  
25 a direction perpendicular to the channels' length with a dicing machine as shown in FIG. 4. The dicing exposes the natural non-wetting or less wetting output face of the polymer. FIG. 4 illustrates a planar cut of the output end 20 of the device of FIG. 2 being made with a dicing machine 32. The cut exposes tube ends 26 that are non-wetting, while the tube interior 24 remains wetting due to the coating  
30 received from liquid 28 within the reservoir 30. The cut tube fragments 34 are discarded.

With a device made of a naturally wetting material, such as glass is to water, the output portion of the device which has been cut and finished may be pressed against a rubber stamp coated with a non-wetting coating, for example a silane having a  $\text{CF}_3$  termination, octadecyltriethoxysilane (OTS), or polydimethylsiloxane (PDMS). The silane is transferred to the output face of the device, making the surface non-wetting. The interior of the channels made of glass are naturally wetting. Alternatively, the output end may be dipped into a solution that imparts non-wetting characteristics such as fluorodecyltrichlorosilane solution, for example, while gas flow is injected into the input end of the capillary array to prevent the solution from entering the channel interiors. This way, the output face obtains a non-wetting characteristic, while the channel interiors remain uncoated, and thereby retain their wetting characteristic.

Once formed, the operation of a device whether made of an organic polymer or glass is substantially the same. In operation, fluid is loaded into the input end of the device. The input is compatible with macroscopic fluid loading, and loading may be accomplished through any variety of known means including: pipette, syringe, pumps, multiple pipette or syringe systems, funnels, etc. Preferably, the center spacing between channels at the input end preferably corresponds to the center spacing of a multiwell plate, a 1536 well plate for example. This way, fluids contained individually in each well of a 1536 well plate may be loaded by forcing the fluid through a hole in the bottom of each well in the 1536 well plate into corresponding channels in the capillary reservoir device. Each channel is self contained, so potentially 10,000 different fluids can be loaded into the device. It is important to note that the number of channels is entirely variable and the number 10,000 was chosen simply as an example of a preferred embodiment.

Each channel's volume is determined by its internal dimensions including the height of the device. Ideally, each channel will contain 5 to 500 microliters, but any volume is possible as determined by the variable dimensions: pitch of channel at top and bottom, and height of the device.



Ideally, the pitch of the channel at the output end is such that liquid will be retained within each channel by capillary force. This way, liquid will remain in each channel until forced out by some external force. One way of forcing liquid through the capillary is through the use of photon pressure to valve the capillaries. In such an embodiment, and as described in French patent appl.#, an optical pulse is sent through an optical fiber and a microlens through a window in each capillary. The photonic pulse elicits the formation of a droplet from the output end of each capillary that has been designated. Other methods for extracting a droplet from the output end of the capillaries include: external pressure such as a vacuum at the output or a positive pressure at the input end, mechanical pressure, acoustic pressure, magnetic pressure, heating, or any other method that would provide constant displacement among the channels.

In a preferred embodiment, each channel is filled with a different binding entity held within a liquid matrix. "Binding entities" are generally termed as a biological or synthetic molecule having a specific affinity for another molecule, through covalent bonding or non-covalent bonding. Preferably, a specific binding entity contains (either by nature or by modification) a functional chemical group (primary amine, sulfhydryl, aldehyde, etc.), a common sequence (nucleic acids), an epitope (antibodies), a hapten, or a ligand, that allows it to covalently react or non-covalently bond to a common function group on the surface of a substrate. Specific binding entities include, but are not limited to: deoxyribonucleic acids (DNA), ribonucleic acids (RNA), synthetic oligonucleotides, antibodies, proteins, peptides, lectins, modified polysaccharides, synthetic composite macromolecules, functionalized nanostructures, synthetic polymers, modified/blocked nucleotides/nucleosides, modified/blocked amino acids, fluorophores, chromophores, ligands, chelates and haptens. The term "biomolecule" and "binding entity" are interchangeable for purposes of this disclosure.

It should be noted that application for this device are not limited to biological materials, but may extend to any chemistry capable of being in liquid form or in a suspension including but not limited to emulsions, particle suspensions, and coacervates. In fact, a reservoir device made from PYREX is capable of printing an array of a liquid that has been heated up to 500°C. This

has potential implications in chemical applications such as printing room temperature semiconductors, dispensing hot pigments or hot waxes, and other nanoengineered microcomponents.

The liquid that contains the binding entity is preferably an acrylamide monomer, but may be any biocompatible polymerizable material. The acrylamide provides the necessary cross-linking required for DNA or other biomolecule immobilization. In a preferred embodiment, 10,000 different acrylamide solutions, each containing an oligomer of slightly different nucleotide sequence are loaded into each channel through means of a multiwell plate as previously described, by multiwell pipette, syringe, etc. Droplets will be elicited from each channel simultaneously by means of photon pressure, external pressure, etc. The drops are contacted against the substrate and thereby deposited. Next, the acrylamide is preferably polymerized by ultra-violet radiation immediately after deposition onto the substrate. The resultant array of polymerized drops is characterized in that the pitch between drops on the substrate is substantially identical to the pitch between channels on the output face of the device. Each droplet occupies an identifiable position in the overall array, and the biomolecules within each drop are covalently bound to the polymerized acrylamide. The biomolecules, in this embodiment - oligonucleotides, are covalently bound to the codeposited polymerized acrylamide.

Any conceivable substrate may be employed in this invention. The substrate may be biological, nonbiological, organic, inorganic, or a combination of any of these, existing as particles, strands, precipitates, gels, sheets, tubing, spheres, beads, porous beads, containers, capillaries, pads, slices, films, plates, slides, membranes, etc. The substrate may have any convenient shape, such as a disc, square, rectangle, sphere, etc. The substrate is preferably flat, but may take on a variety of alternative surface configurations. For example, the substrate may contain raised or depressed regions on which liquid is deposited. Further, the substrate may be glass, polymer or membrane into which channels have been etched; or it may contain regions that have been made porous by means of a chemical etchant. The substrate and its surface preferably form a rigid support on which a liquid with the appropriate surface energy and containing a binding entity

can be deposited, and which is preferably functionalized with an organosilane such as gamma-aminopropyl triethoxysilane or methacryloxypropyltriethoxysilane, for example.

In a preferred embodiment, the substrate is flat glass, preferably a borosilicate glass having surface relief features of less than 10 nanometers. Although a non-patterned plate is preferred for droplet alignment issues, the surface of the glass substrate may be coated with a non-wetting agent such as fluorodecyltrichlorosilane or ocyadecyltrichlorosilane, for example. The coating may be selectively removed by using known methods of photoresist or selectively applied using masking techniques. Preferably, an array of positions that are uncoated and thereby wetting is presented. The spacing in the wetting/non-wetting positional array preferably corresponds to the spacing between channels on the output face of the capillary reservoir device. This way, drops need only contact the exposed wetting positions on the substrate for drop transfer. The drops are drawn into the center of the wetting position by physical and chemical means. Crosstalk is eliminated by the wetting characteristics of the substrate. Alternatively, a patterned etching process may create positions within the substrate and below the substrate surface that form a matrix of porous glass regions which may also serve to eliminate the potential for crosstalk. Drops may be deposited within the porous regions which preferably align with the channel spacing on the output face of the capillary reservoir device.

### **Printing Methods**

Printing a matrix of droplets of acrylamide containing oligonucleotides directly from the capillary reservoir device, and with a spacing of less than 200  $\mu\text{m}$  apart, may require a specific process in order to reduce the potential of neighboring droplets from spreading and combining, i.e. crosstalk. The printing process comprises the steps of: providing a capillary reservoir device having a non-wetting fluorinated treatment on the output plane and the sidewalls; filling at least one channel of the capillary reservoir device with an acrylamide/biomolecule mixed solution; providing a functionalized glass substrate, for example a substrate coated with an organosilane such as

methacryloxypropyltriethoxysilane; and, transferring a droplet from the output of each channel in the device by contact with the substrate in an environment of zero or negative capillary pressure.

An acrylamide/oligonucleotide solution has a medium range surface tension of approximately 52 mN.m<sup>-1</sup> and a relatively low contact angle on glass substrates functionalized with methacryloxypropyltriethoxysilane, for example, of approximately 50 degrees. Contact angle is a direct measure of surface energy. With a contact angle of 50 degrees, it is not possible to avoid droplet mixing between individual droplets spaced 100 µm or less apart on the substrate prior to curing. Furthermore, contact angles below 90 degrees create, upon transfer, a positive capillary pressure between the capillary reservoir device and the glass substrate which causes the oligonucleotides in the liquid droplets to spread into the gap separating the output end of the capillary reservoir device and the substrate. Therefore, a negative or zero capillary pressure environment is preferred in order to limit crosstalk during drop transfer. In order to achieve a negative or zero capillary pressure environment between the device and the substrate, contact angles equal to or higher than 90 degrees are required on both the output face of the reservoir device and the substrate surface. For the capillary reservoir device, the fluorination treatment previously described satisfies this condition.

For the substrate, the proper contact angle may be achieved by accomplishing the drop transfer from the capillary device to the functionalized substrate in an environmental immiscible liquid medium other than air. Because the oligonucleotides are based in an aqueous solution, alkanes or hydrocarbons satisfy the condition of immiscibility. As an example, the contact angle of the amine functionalized substrate with respect to the oligonucleotide/acrylamide solution is increased from 50 degrees in air to 100 degrees in dodecane. Under these conditions, the spreading of the oligonucleotide/acrylamide droplets is limited and the capillary pressure is negative. By immersing the substrate in the hydrocarbonated liquid, the surface tension of the substrate is substantially reduced compared to air. The contact angle of the oligonucleotide/acrylamide

solution to the channels of the reservoir device is also increased, thereby creating favorable conditions for the droplet transfer.

After transfer, the immiscible liquid environment further provides an oxygen free environment for the oligonucleotide/acrylamide droplets to be cured to the substrate. This is an important advantage over open air transfers because the acrylamide polymerization is very sensitive to oxygen inhibition.

In order to increase the contact angle of the functionalized substrate with respect to the oligonucleotide/acrylamide solution to 90 degrees or more, droplet transfer in an immiscible liquid medium having a surface tension of about 35 mN. m<sup>-1</sup> at 20°C is preferred.

It has been observed that it may be advantageous to store the functionalized substrate for one hour in the hydrocarbon environment before initiating droplet transfer from the capillary reservoir device. This step allows for the use of hydrocarbonated liquids having a surface tension, K, of 25 mN. m<sup>-1</sup> or greater at 20°C. Table 4 is a non-exclusive listing of hydrocarbons that may be used to provide the proper environment for the oligonucleotide/acrylamide droplet deposition onto a substrate.

Table 4

Hydrocarbon	Surface Tension K at 20°C (mN. m <sup>-1</sup> )
Dodecane	25.4
Tridecane	26.0
Tetradecane	26.6
Pentadecane	27.1
Hexadecane	27.5
Cyclohexane	25.2
Decahyronaphthalene	31.1
Bromonaphthalene	44.4

It should be noted that the process of drop transfer from one medium to another in an environmental immiscible liquid may be performed for any number

of differing droplet chemistries and substrates, and may vary according to the chemistry of the droplet as well as the chemistry of the substrate. It may be used wherever low surface tension liquids are being transferred in order to prevent the droplet spreading on the substrate. After the drop is cured, the plate can be warmed up to approximately 60-65°C in order to evaporate the solvent and/or the environmental hydrocarbon.

One way of avoiding the need for a negative capillary pressure environment is to create a reservoir device that is designed in such a way as to maintain a constant fluid level at the output end. In explaining the basic concept of how this may be accomplished, the focus will be upon a single channel in the device. In this embodiment, the reservoir is bent after redraw such that the output face and input face are in the same horizontal plane and the entire device is U-shaped. Further, each individual channel is U-shaped, as shown in FIG. 14 which is a cross sectional view of one channel from the device, and has a predetermined radius ( $r_2$ ) at the input end 82 and a predetermined radius ( $r_1$ ) at the output end 84. The liquid may either bead on the output of the channel or form a meniscus within the channel depending on the capillary pressure, density of the liquid and head height as determined by the contact angle. For purposes of this disclosure, whether the liquid beads or not is not important, but in the following examples, the liquid forms a meniscus in the channel.

A pin from a typographic pin plate, for example, is inserted into the channel at the output end of the device in order to pick up a liquid droplet, which in turn is contacted to a substrate thereby creating the array.

As can be observed,  $r_2$  is greater than  $r_1$ . Liquid, such as DNA probe solution to be printed, is loaded into the input end 82 of the channel. A pin having a radius that is slightly smaller than  $r_1$  contacts the liquid by entering the output end 84 of the channel. A liquid droplet, of volume  $v$ , is elicited from the channel by surface tension on the pin surface and transferred to a substrate. Due to capillary pressure, the level of liquid in the channel does not drop on the output end. The level of liquid on the input end of the device drops by the volume of the drop that has been removed, while the level of the liquid at the output end of the device remains the same. This phenomenon is a result of the capillary pressure

between the output end of the channel and the input end. The capillary pressure is equal to  $2\gamma (1/r_1 - 1/r_2)$ , where  $r_1 < r_2$ , and where  $\gamma$  is the liquid surface tension. The pressure allows the removal of a volume of liquid,  $v$ , at the output end of the channel, without affecting the level of the liquid at the output end. Liquid will be reduced on the input end of the device, while remaining constant on the output end of the device, until the difference in height between the two ends of the capillary,  $H$ , reaches the capillary height defined by:  $2\gamma / \rho g (1/r_1 - 1/r_2)$ , where  $\rho$  is the liquid density and  $g$  represents gravity ( $9.81 \text{ m.s}^{-2}$ ). The total volume,  $V$ , that may be extracted from the channel before the liquid level on the output end begins to drop is given by the equation:  $V = 2\pi r_2^2 \gamma (1/r_1 - 1/r_2) / \rho g$ . The number of possible transfers to a typographic pin from this channel is equal to  $V/v$ .

It should be noted that it is not necessary that the input end and output end be in the same horizontal plane. The output end can be lower than the input end, but the distance between the two ends,  $h$ , must be less than the capillary height,  $H$ . When the output and input ends are in the same plane ( $h = 0$ ),  $V$  is at a maximum.

As an example, assuming the input end and the output end are in the same plane ( $h = 0$ ),  $r_1 = 50 \text{ }\mu\text{m}$ ,  $r_2 = 300 \text{ }\mu\text{m}$ ,  $\gamma = 50 \times 10^{-3} \text{ N.m}^{-1}$ , and  $\rho = 10^3 \text{ kg/m}^3$ ; then the volume of DNA probe solution available,  $V$ , while retaining a constant level in the output end of the channel, is equal to  $48 \text{ }\mu\text{l}$ . If the typographic plate used to transfer liquid from the output end of the device to a substrate plate has pins having a radius in the order of  $40 \text{ }\mu\text{m}$ , the volume of individual droplets will be  $80 \text{ pl}$ . Therefore, the channel will allow for 600,000 pin transfers of liquid while the liquid level on the output end of the channel remains constant.

Obviously, the complete reservoir device would be comprised of a plurality of channels having the described U shape. The number of capillaries will correspond to the number of sites in the desired array. An example of a printing tool **90** that employs the bent device is shown in FIG. 15. The bent reservoir device **92** is housed in a boxed unit **94** such that the output face **96** and input face **98** of the device are in approximately the same plane. A typographic pin array **100** having a matrix of pins aligned such that each pin from the matrix

fits into a corresponding channel from the output face 96 of the reservoir device 92 is mounted on a flexible stainless steel flextem 102. A string 104 attaches a lever 106 with the top surface of the flextem 102 such that when the lever is actuated, the pin plate 100 contacts the output face 96 of the device such that each pin enters each channel, contacts the liquid therein and is thereafter removed.

FIG. 16 shows a cross sectional portion of the pin plate 100 of FIG. 15 as it interacts with the output face 96 of the device. Individual pins 101 contact liquid 103 from individual channels 105. The pin plate 100 is removed from the channels 105 pulling a drop 107 of liquid from each of the channels; the drops are affixed to the ends of the pins 101, as shown in FIG. 17. After the drop 107 is removed, the liquid level remains at the top of each channel 105. A properly prepared substrate is then placed under the pin plate 100; after which, the pin plate is contacted to the substrate surface thereby depositing an array of drops. FIG. 18 shows a partial cross sectional view of a substrate 108 having a plurality of drops 110 that have been deposited thereon by the pin plate 100.

It is not necessary to employ a U-shaped structure in order to obtain a constant level on the output end of the reservoir. A cross section of the printing tool of FIG. 15 containing the U-shaped reservoir device is shown in FIG. 19. Two alternative capillary reservoir designs are shown in FIGS. 20-21. The U-shaped reservoir 92 of FIG. 19 having an input face 98 radius of  $300\mu\text{m}$ , an output face 96 radius of  $50\mu\text{m}$ , and a length of 200-400 mm, is ideal for containing 50-100 $\mu\text{l}$  of liquid and printing approximately 500,000 – 1,000,000 drops of approximately 80 pl/drop. FIG. 20 is an example of a reservoir device having a conical design 120 whereby the input ends of the channels making up the device are filled with the chosen liquid mixture. The device is then flipped over so that the output end 122 of the device faces upward. The liquid will be retained within the channels due to capillary pressure, and the liquid level will remain constant at the output end of the device even after droplets have been drawn from the channel. In this design, assuming the same output and input face radius as above, but having a channel length of 20-50 mm, each capillary



reservoir (channel) contains 2-10 $\mu$ l of printable liquid, which translates into approximately between 20,000-100,000 drops of 80 pl/drop.

FIG. 21 shows another alternative design of the device. This design allows for greater volume storage than the channel design of FIG. 19, but less than is allowed in the U-shaped design. This L-shaped device 124 works substantially in the same way in that each reservoir is filled through the input face 126 of the device and droplets are drawn from the output end 128 of the device, by pin plate for example. As in the examples above, the liquid level at the output end remains constant. In this design, assuming the same output and input face radius as above, but having a channel length of 50-200 mm, each capillary reservoir (channel) contains 10-50 $\mu$ l of printable liquid, which translates into approximately between 100,000-500,000 drops of 80 pl/drop.

It should be noted however, that smaller volumes of liquid may be loaded into these devices; the liquid will be driven by capillary forces to the output end of the device. The stated ranges are only suggested volumes and are not intended to be limiting to each embodiment.

### **Printing Beads**

Often, biomolecules such as oligonucleotides or peptides are synthesized on low cross-linked polystyrene beads or other polymeric supports by methods described and referenced by S.R. Wilson and A.W. Czarnek in *Combinatorial Chemistry, Synthesis and Application* (1997). This type of synthesis is called solid phase synthesis and it is by this means that extremely large libraries of biomolecules or other sequentially or combinatorially produced molecules can be synthesized and identified. The synthesized biomolecules are routinely cleaved from the bead at the completion of the synthesis process.

In this embodiment, molecules that have been synthesized by solid phase synthesis are not cleaved from the support beads. Instead, they are incorporated, in suspension, along with an appropriate solvent in order to create a printable liquid. In order to retain the ability to remain in suspension while still

minimizing any potential steric interaction problems, the biomolecules are preferably synthesized on beads that are between 0.3 and 0.6  $\mu\text{m}$  in diameter.

The suspension is printed onto a substrate by the method disclosed above. Preferably and by means of an example, the substrate is glass with a vinyl silane coating and the beads are vinyl benzene cross-linked in divinyl benzene. Each channel of the capillary reservoir device is filled with a different known biomolecule covalently attached to a plurality of beads such that, within any one channel, there are a plurality of identical biomolecules attached to a plurality of beads. The suspensions containing the beads are printed into an array at predetermined attachment positions either on the substrate surface, or within microwells or channels within the substrate. Once printed, the vinyl group from the vinyl silane covalently reacts with the styrene (vinyl benzene) in the bead thereby immobilizing the bead to the substrate surface. The molecules themselves remain immobilized on the bead. It is contemplated that other materials may be used for the beads and for the substrate in order to take advantage of such a covalent bead-substrate immobilization interaction.

In an alternative embodiment, molecules are synthesized on beads that are sized such that only one bead at a time will fit through the output of any individual channel of the device. This way, a single bead may be printed at each position on the array. Each individual bead contains at least one molecule attached thereto, while the bead itself attaches to the substrate. In this embodiment, the sizing of the bead is dependent on the diameter of the channels at the output end of the capillary reservoir device that is employed in the printing.

In yet another embodiment, non-reacted beads are deposited on a substrate in an array. Combinatorial or sequential synthesis can then be performed on the immobilized beads.

#### Slice Array

Another embodiment of the present invention involves a technique that eliminates the need for liquid handling as between the capillary reservoir device and a substrate. In this embodiment, a capillary reservoir device that preferably has 1,000 or more channels and is preferably comprised of an organic polymer

such as polystyrene, is redrawn down (as shown in FIG. 6) to a predetermined size and elongated such that a reduced linear portion 40 of substantially uniform cross sectional size is created at the outlet end 42. Each channel of the resultant redrawn device 48 is then filled with a liquid. Each liquid is a different mixture of a particular binding entity and a thermally activated curing polymer such as an epoxy resin (EPON). As an example, each channel may contain a different aminated oligonucleotide or cDNA which is combined with the epoxy resin. An epoxide group from the epoxy resin will covalently react with the amine creating a crosslinked polymer network. A different known oligonucleotide or cDNA fragment is selected for each individual channel and combined with the epoxy. The various mixtures are entered into the many channels, the entire device is cured, for example in a 6 hour cycle at 40°C, or more preferably 2 days at room temperature in order to limit gas production caused by the polymerization reaction. FIG. 7 shows the device of FIG. 6 undergoing a curing step. The curing may be performed by gamma radiation, blue light, temperature activation, or room temperature curing, for example.

After curing, the reduced sized portion 40 is cut from the rest of the device and preferably frozen down to -40°C, below the polymer glass transition temperature. The freezing step makes the epoxy matrix and polymer brittle thereby facilitating a clear cut by fracturing. Cutting by fracturing reduces the chance of crosstalk contamination as between neighboring channels as the blade passes through. Further, deformation or distortion of the array is prevented with this type of cutting technique.

The reduced size portion 40 may then be chopped into blocks 50 as shown in FIG. 8. FIG. 9 shows very fine slices 54 being cut from a frozen block 50 with a tomography cutting tool 52, such as a diamond blade or glass blade, for example. Each slice 54 is preferably approximately between 4 and 10 Tm in thickness, although any slice thickness may be possible. Each slice also contains, for example, 10,000 different binding entities suspended in the cured epoxy resin matrix as a result of the channel filling. The slice takes the form of a sheet comprising a lattice network formed by the channel walls and defining a plurality

of containment spaces each having sidewalls and an open top and bottom, and a different known binding entity occupying each containment space.

After the slicing, the slice 54 is bonded to a preferably flat substrate slide 56, as shown in FIG. 10, preferably made of either glass or an organic polymer, by means of ultrasonic welding or gluing, for example. The walls of the channels serve as boundaries for elimination of crosstalk between samples. Further, the material of the capillary reservoir device is preferably opaque, and more preferably black. This way, optical crosstalk that often results as a consequence of fluorometric, chemiluminescent or colorimetric assays may be reduced as between different samples. Bar coding 57 may be employed as a means of recording the contents of each well or position on the array. Proper alignment of the slice on the substrate can be assured by a feature such as a beveled edge (not shown).

Once bound to the substrate, the slide may be packaged for transport and subsequent use in any variety of research or diagnostic procedures.

It should be noted that as in the method described above, the liquid suspension including synthesized biomolecules covalently attached to beads may be used along with the resin to fill the channels and become part of the polymer network upon curing.

#### Assay Plate Reformatting

Another embodiment of the present invention involves its use in reformatting assay plates. For many years, multi-well laboratory plates have been manufactured in configurations ranging from 1 well to 96 wells. The wells of multi-well plates are typically used as reaction vessels for performing various tests, growing tissue cultures, screening drugs, or performing analytical and diagnostic functions. Industry standard multi-well plates are laid out with 96 wells in an 8 x 12 matrix (mutually perpendicular 8 and 12 well rows). In addition, the height, length and width of the 96-well plates are standardized. This standardization has resulted in the development of a large array of auxiliary equipment specifically developed for 96-well formats. The equipment includes devices that load and unload precise volumes of liquid in multiples of 8, 12, or

96 wells at a time. Recently, as sample sizes have been reduced to microliter levels and the demand for a greater number of tests per plate has increased, the number of wells on a plate have likewise increased, e.g. from 384 wells to 1536 wells and above. In order to accommodate the existing auxiliary equipment, the standard plate footprint has remained the same, while the well density has increased. The higher density plates predominately have a number of wells that are a multiple of the standard 96. These plates have well spacing that is fractionally based on the center well spacing of a 96 well plate.

One challenge to scientists is how to efficiently and quickly transfer samples that have been prepared in a comparatively lower density plate, such as a 96 well plate, to a plate of comparatively more wells per same unit area, such as a 1536 well plate, for example. Referring to FIG. 11, a redrawn capillary device can be formed having such dimensions that the transfer from a 96 well plate to a 1536 well plate can occur quickly and easily. The input end 60 of the device is sized approximately to the dimensions of an industry standard 96 well plate (3.370 inches by 5.035 inches). 96 channels 62 are spaced in an 8 x 12 matrix (mutually perpendicular 8 and 12 channel rows). The channels align with the wells of the 96 well plate which are spaced approximately 0.355 inches on center. The device is redrawn in a 16 to 1 reduction such that the center spacing between channels on the output end 64 approximately equates to the center spacing between wells of a 1536 well plate (0.089 inches). The wells of a 1536 well plate are spaced in a 48 x 32 matrix (mutually perpendicular 48 and 32 well rows). It would take 16 of the 96 well plates to fill a plate having 1536 wells. The samples that have been transferred will have an ordered orientation. In other words, the 1536 well plate can be divided into a matrix of 4 rows and 4 columns, each location in the matrix containing the samples from a single 96 well plate in their original orientation.

In FIG. 11, a 96 well filter plate 68 is aligned over the input end 60 of the device. Each well from the 96 well filter plate 68 aligns with a channel from the device. Samples from the 96 well filter plate are loaded into each channel 62. The output end 64 of the device is then located over a portion of a 1536 well plate 66 as shown in FIG. 12 such that channels on the output end 64 align with wells

of the 1536 well plate. Sample is then expelled from each channel into individual wells of the plate 66.

The output end of the device may be fitted with multiple syringe needles or pipette tips to facilitate transfer.

5           Use of this transfer method is especially beneficial for dispensing large numbers of samples in compiling multiple copies of a compound library, for example.

10           The capillary device used as a transfer tool works equally well for transfers between a 96 well plate and a 384 well plate. The reduction during redraw in this case is 4 to 1. The 384 well plate can contain the samples from four 96 well plates in a 2 X 2 matrix. The capillary device may be employed to deliver samples from a multiwell plate of having any number of wells to a plate having a larger number of well per unit area. The device may even be employed in the reverse, to transfer samples from a 1536 well plate to a 96 well plate, for  
15           example.

          Further, sealing means can be provided that can cover both the loading or input end of the device and the output end of the device. Such a seal will prevent evaporation and create favorable storage conditions. Examples of sealing means include snap-on lids, heat sealed wraps, rubber mats, pressure sealing tape, or any  
20           other sealing mechanism known in the art.

          Further, the reformatting tool can be used as between a 384 well plate and a 1536 well plate; or even from a 1536 to a flat substrate. The reformatting tool can be used as between any two plates of differing well density, so long as the matrix pattern defined by the pitch between wells in the plates is scaled.

25           Semi-conductor micro-fabrication may be accomplished using the redraw and printing technology disclosed herein.

          Although the invention has been described in detail for the purpose of illustration, it is understood that such detail is solely for that purpose and variations can be made therein by those skilled in the art without departing from  
30           the spirit and scope of the invention which is defined by the following claims.

**What is Claimed:**

1. A device for depositing an array onto a substrate comprising:  
5 a plurality of channels collectively forming a matrix having a top and bottom of predetermined cross sectional area, each channel having walls defining an open inlet of predetermined cross sectional area and an open outlet of predetermined cross sectional area;  
said cross sectional area of said inlet being greater than said cross  
10 sectional area of said outlet; and  
the cross sectional area of any one channel as a proportion of the cross sectional area of said matrix being substantially identical on said top and said bottom, and whereby a liquid is capable of being retained in at least one of said channels by capillary force.
- 15 2. The device of claim 1 wherein said channels have interior walls having a wetting surface and said bottom is a non-wetting surface.
3. The device of claim 1 further comprising a removable closure over  
20 said top and said bottom.
4. The device of claim 1 wherein said device is comprised of an organic polymer.
- 25 5. The device of claim 1 wherein said device is comprised of an inorganic polymer.
6. The device of claim 5 wherein said inorganic polymer is glass.
- 30 7. The device of claim 1 wherein said bottom of said matrix is approximately 1 inch square.

8. The device of claim 1 wherein said matrix contains approximately 10,000 channels.

5 9. A tool for transferring liquid from a first multiwell plate having a predetermined density of wells per unit area to a second multiwell plate having a proportionally greater density of wells per unit area comprising:

a plurality of channels collectively forming a matrix having a top and bottom of predetermined cross sectional area, each channel having an open input face of predetermined cross sectional area and an open output face of  
10 predetermined cross sectional area

said matrix being shaped such that said cross sectional area of said matrix bottom is smaller than said cross sectional area of said matrix top;

said input faces of said channels having substantially identical spacing to the spacing of said wells of said first multiwell plate such that said wells align  
15 with said input faces; and

said output faces of said channels having substantially identical spacing as that of said wells of said second plate such that a portion of said wells from said second multiwell plate align with said output faces.

20 10. The tool of claim 9 wherein said matrix contains 96 parallel channels.

11. The tool of claim 9 wherein said matrix contains 384 parallel channels.

25 12. The tool of claim 9 wherein said matrix contains 1536 parallel channels.

30 13. A method of depositing an array of liquid drops onto a substrate surface comprising the steps of:

- a) providing the tool of claim 1
- b) depositing liquid into at least one said channel



c) contacting at least one drop of said liquid, extending from at least one said outlet, to said substrate surface.

14. The method of claim 13 wherein said liquid contains a curing agent which, when activated, polymerizes.

15. The method of claim 14 wherein said curing agent is an acylamide.

16. The method of claim 15 including the step of curing the liquid immediately after said deposition.

17. A method of making a form having a plurality of open ended channels extending from an input face to an output face wherein at least along a predetermined length, each channel decreases approximately equally in diameter, cross sectional area, and wall thickness comprising the steps of:

a) extruding a material through a multi-celled die to create a multi-celled honeycomb structure having a predetermined cross sectional shape; and,

b) redrawing at least a portion of said honeycomb structure.

18. The method of claim 17 further including the step of cutting said redrawn portion of said structure in a direction perpendicular to said channels to expose a face having a cross-sectional area less than the cross-sectional area of said extruded honeycomb structure.

19. The method of claim 17 wherein said cross sectional shape is round.

20. The method of claim 18 wherein said cross sectional shape is rectangular.

21. A method of depositing an array of biological samples onto a substrate comprising the steps of:

a) providing a device having a plurality of open ended channels extending from an input face to an output face wherein at least along a length, each channel decreases approximately equally in diameter, cross sectional area, and wall thickness;

b) filling at least one of said channels with a liquid that is capable of hardening under proper conditions;

c) allowing said liquid to harden; and

d) slicing a section of said device.

22. The method of claim 21 further comprising the step of bonding said sliced section to said substrate after said slicing step.

23. The method of claim 21 further comprising the step of freezing the device after said hardening step and prior to said slicing step.

24. The method of claim 22 further comprising the step of allowing the sliced section to thaw after said bonding step.

25. The method of claim 23 wherein said sliced section is 4-10  $\mu\text{m}$  in thickness.

26. The method of claim 23 wherein said slicing step is performed by a microtome.

27. The method of claim 23 wherein said bonding is ultrasonic bonding.

28. The method of claim 23 wherein said substrate is optically clear.

29. The method of claim 23 wherein said substrate is composed of a glass.

30. The method of claim 23 wherein said substrate is composed of a thermoplastic polymer.

31. The method of claim 23 wherein said device is composed of an opaque material.

32. The method of claim 23 wherein said liquid contains a binding entity.

33. The method of claim 31 wherein said binding entity is an oligonucleotide.

34. A method of making a tool for printing biological or chemical samples onto a substrate surface comprising the steps of:

- a) extruding material through a die thereby forming a block having a plurality of parallel channels; and
- b) redrawing said block such that the circumference of said block is reduced.

35. An array of binding entities comprising:

- a) a substrate having a plurality of predetermined attachment positions;
- b) each position comprising a plurality of beads having a plurality of identical known biomolecules covalently attached thereto;
- c) each position representing a different biomolecule; and
- d) said beads covalently attached to said substrate.

36. A block having a plurality of parallel channels extending therethrough, at least one channel having a binding entity contained therein.

37. A sheet comprising:

a lattice network defining a plurality of containment spaces each having  
sidewalls and an open top and bottom, and a different binding entity occupying  
each said containment space.

38. An array of binding entities comprising:

a substrate,

a polymer matrix bonded to said substrate and defining a plurality of  
sample positions, and

sample contained within at least one of said positions.

39. An array of binding entities comprising:

a plurality of wells on the surface of a substrate

said wells having sidewalls

a different binding entity occupying each said well

40. The array of claim 38 wherein said wells are located on said

substrate at a density of at least  $10^3$  wells per  $\text{cm}^2$  of surface area of said surface.

41. An array of binding entities comprising:

a substantially flat first plate;

a second plate having a plurality of open ended wells;

a different binding entity occupying each said open ended well, and

whereby said second plate is bonded to said first plate.

42. An array of binding entities comprising:

the sheet of claim 36, and

a substrate, whereby said sheet is affixed to said substrate.

43. A direct printing process comprises the steps of:

a) providing a device having a plurality of open ended channels extending from an input face to an output face wherein at least along a predetermined length, each channel decreases approximately equally in diameter, cross sectional area, and wall thickness;

b) filling at least one channel of the capillary reservoir device with a liquid;

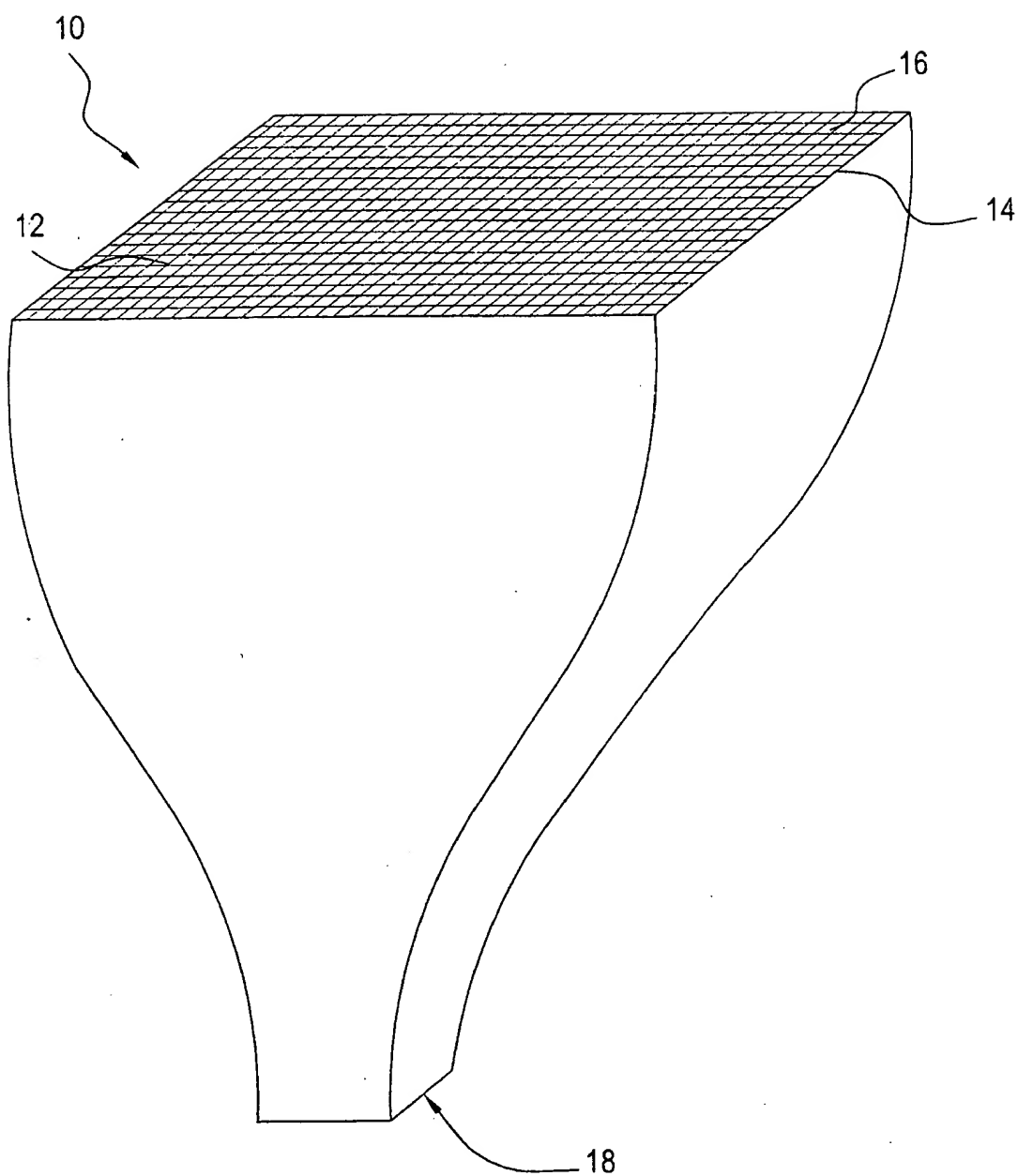
c) providing a substrate;

d) transferring a droplet from the output of each at least one channel in the device by contact with the substrate in an environment of zero or negative capillary pressure.

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FIG.1



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2 / 12

FIG.2

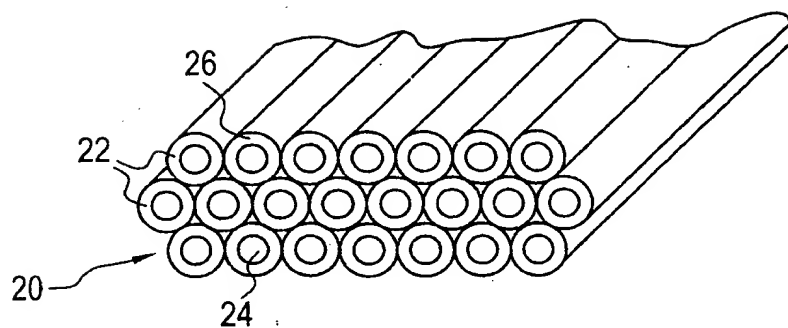


FIG.3

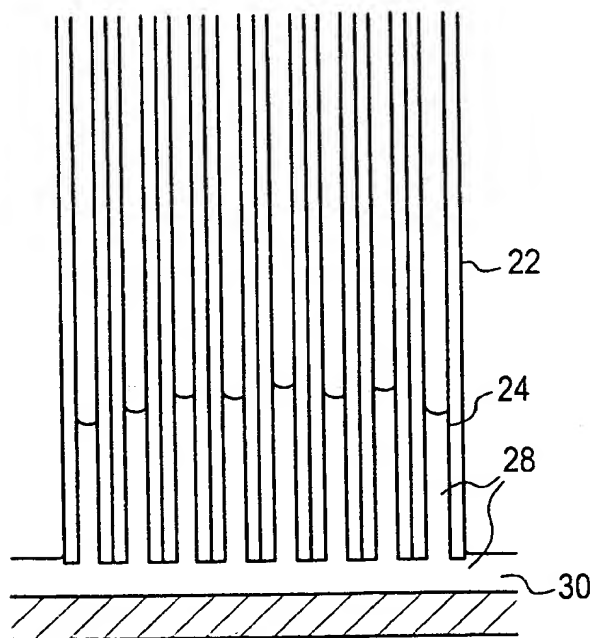
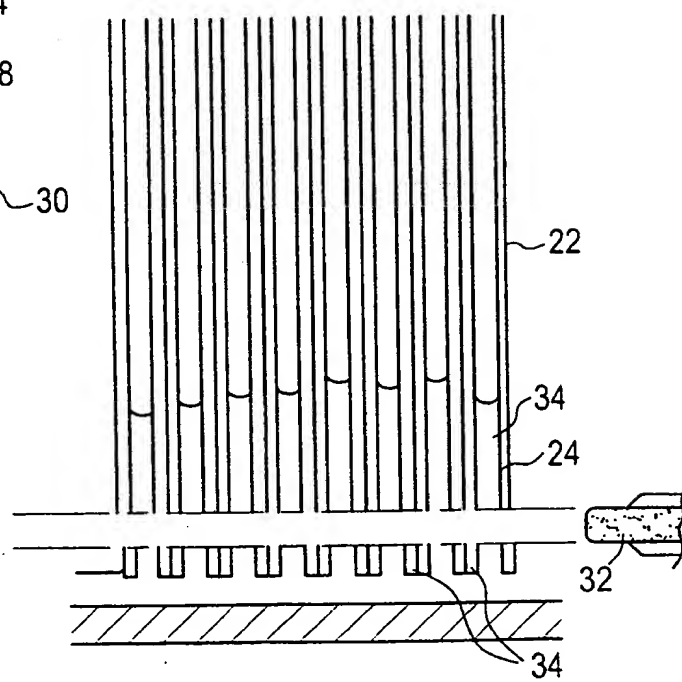


FIG.4



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3 / 12

FIG.5

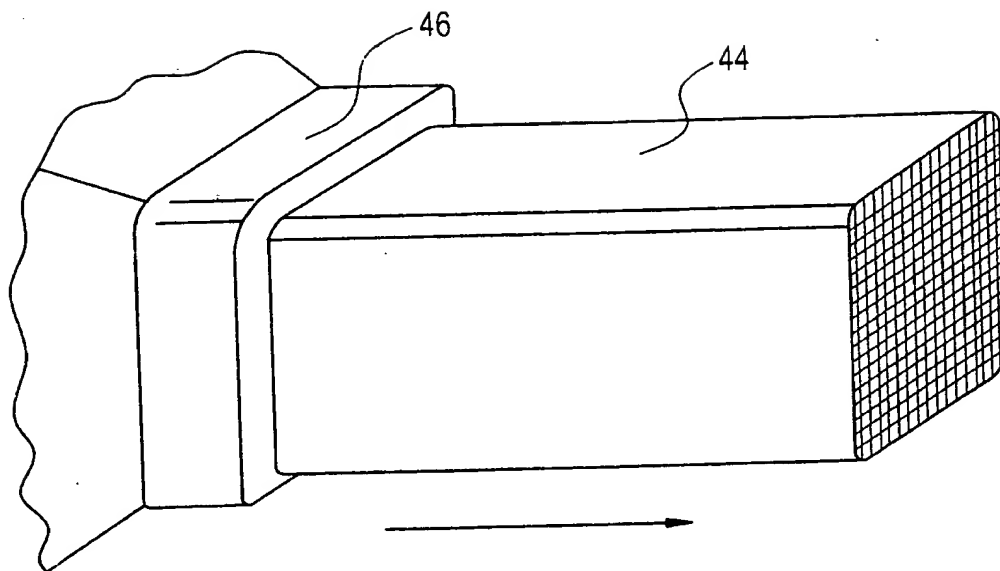
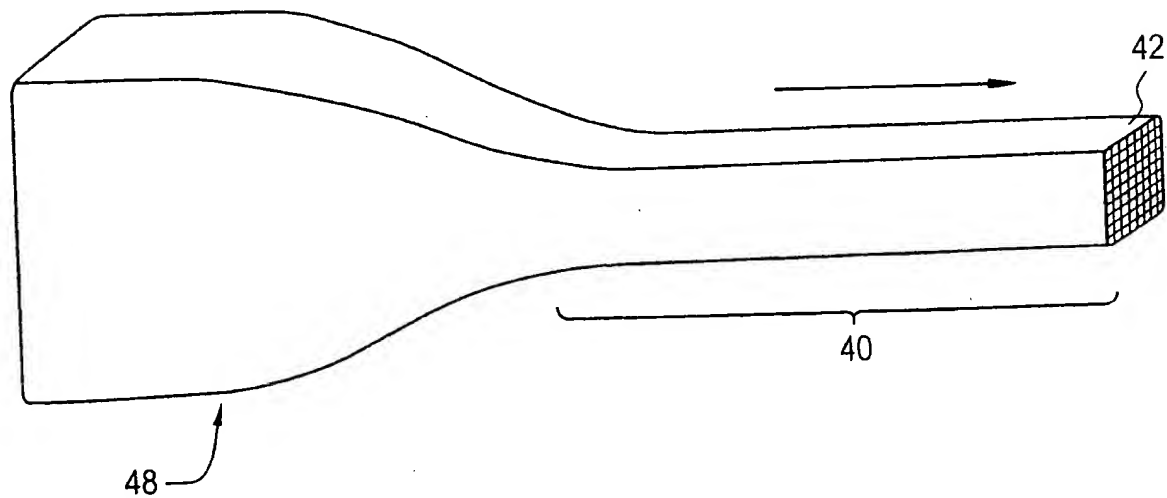


FIG.6



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4 / 1 2

FIG.7

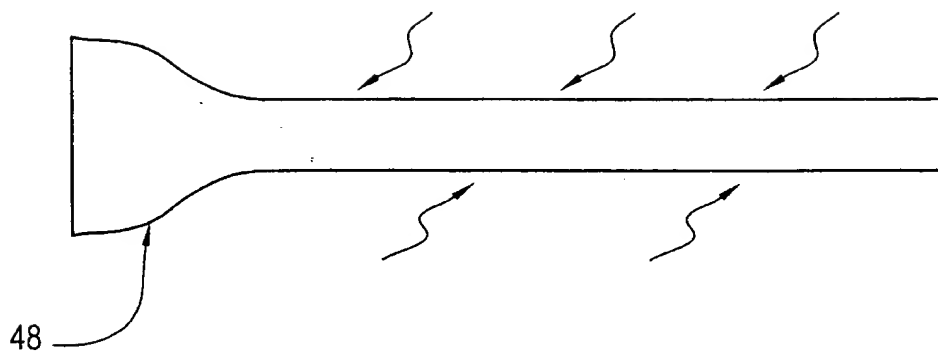
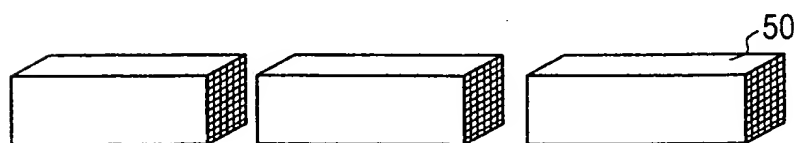


FIG.8



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5 / 1 2

FIG.9

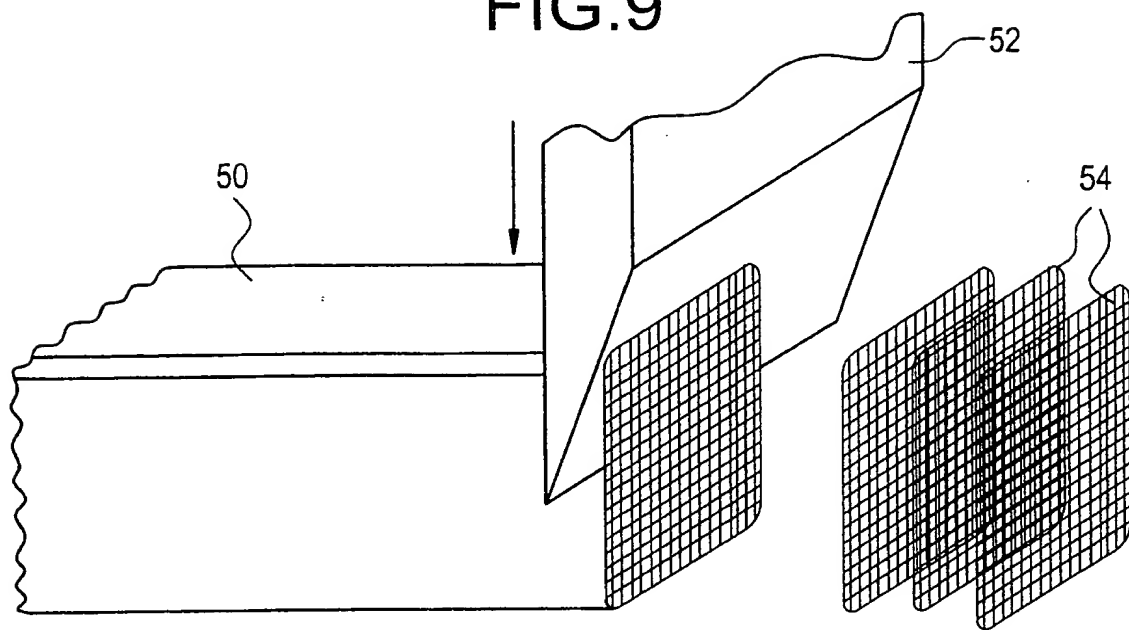
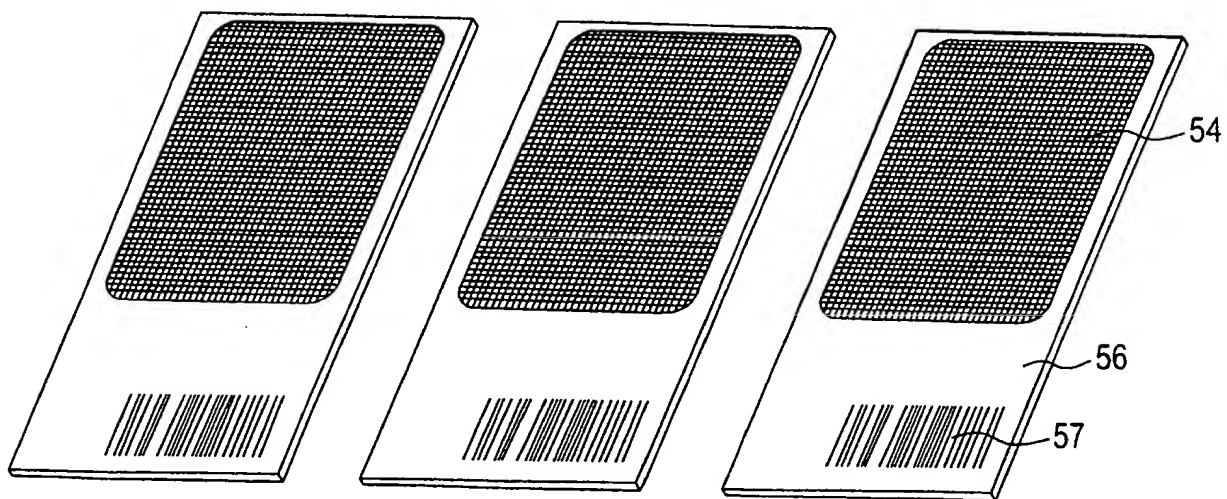


FIG.10

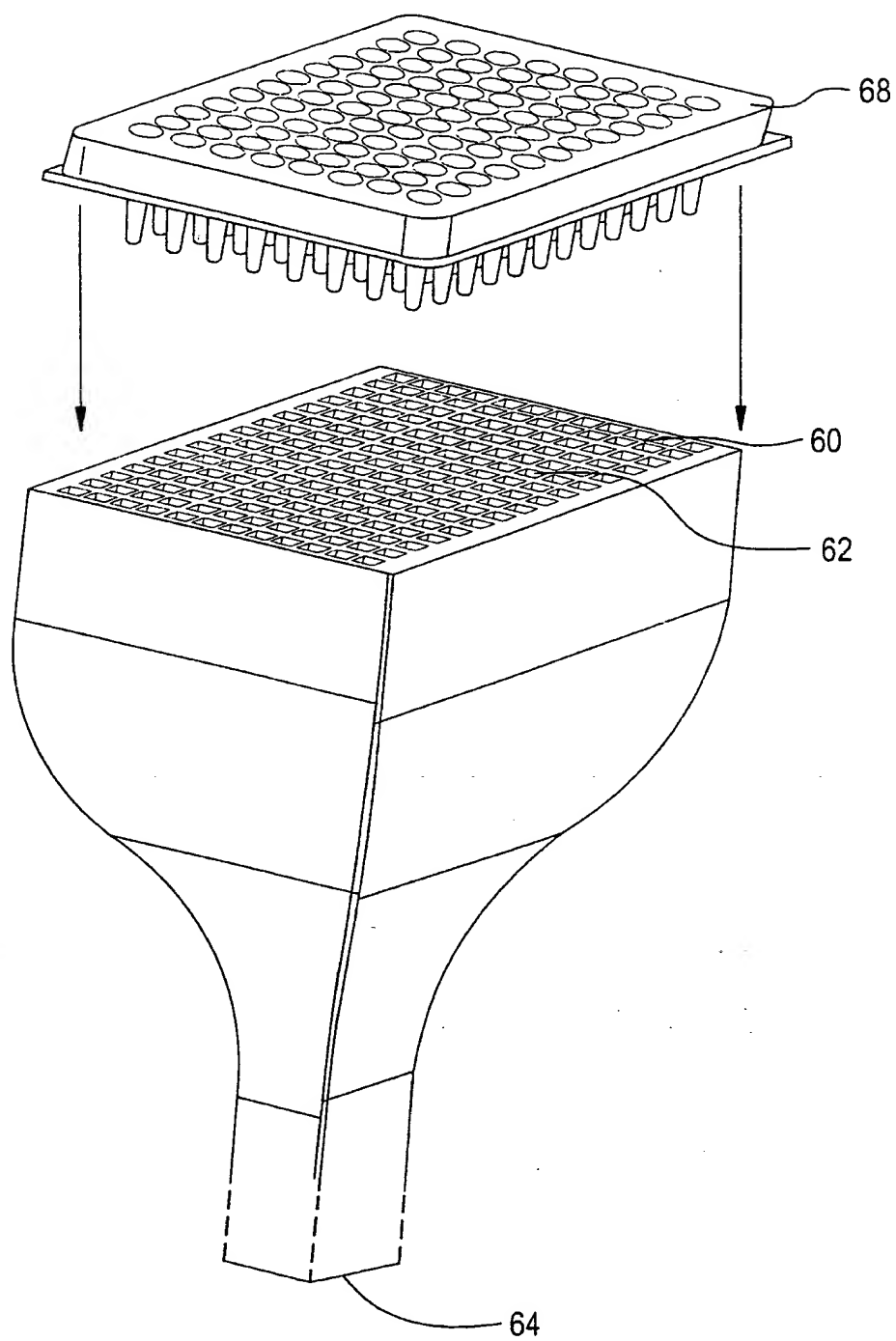


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6 / 1 2

FIG. 11



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7 / 12

FIG.12

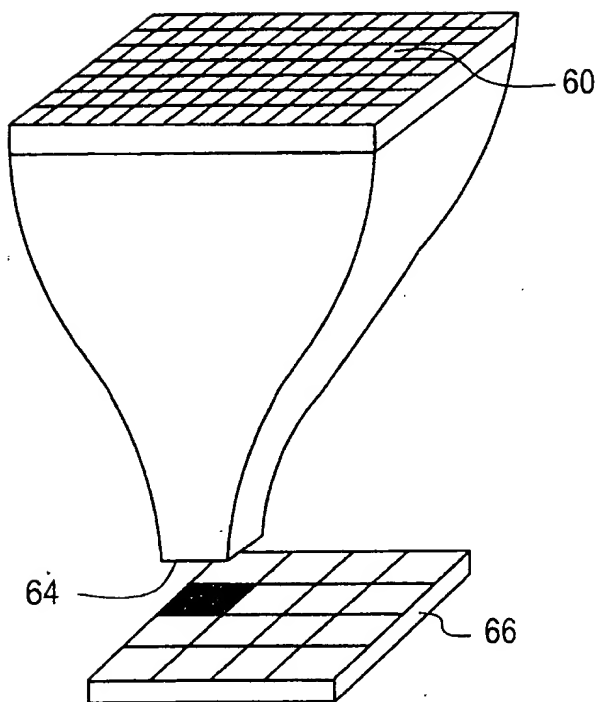
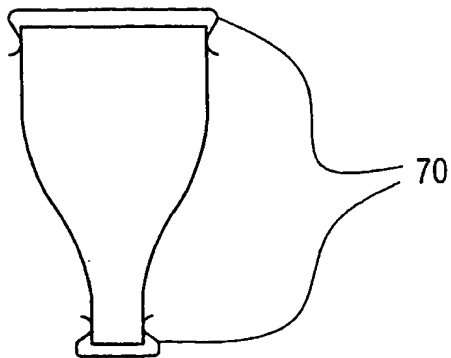


FIG.13



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8 / 1 2

FIG. 14

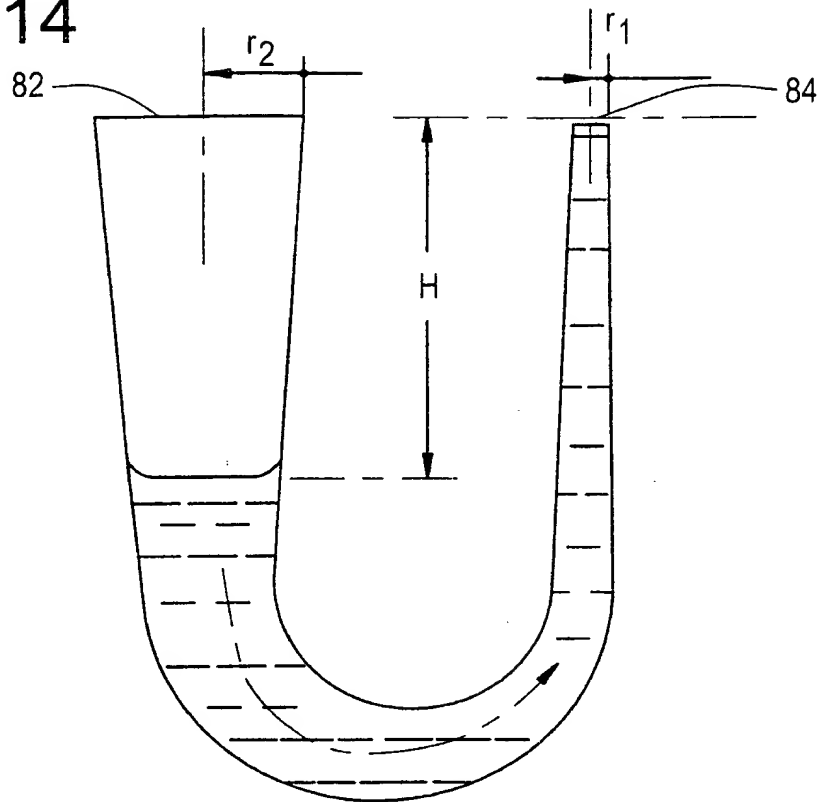
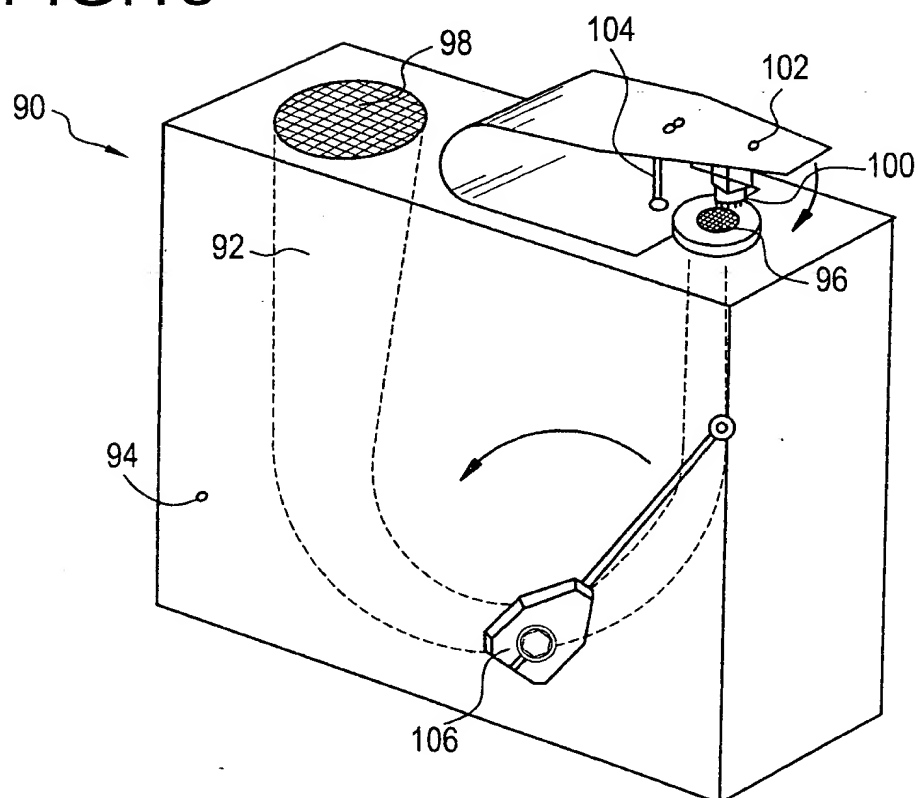


FIG. 15



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FIG.16

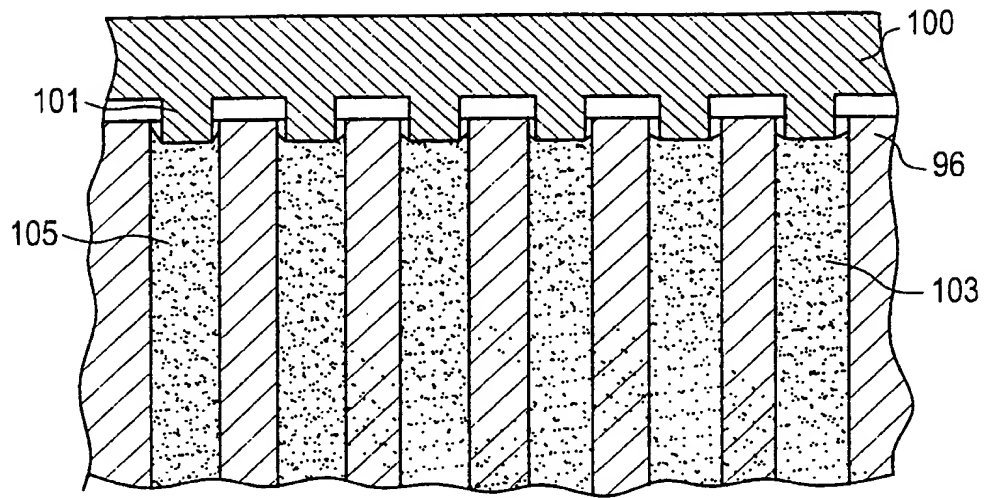


FIG.17

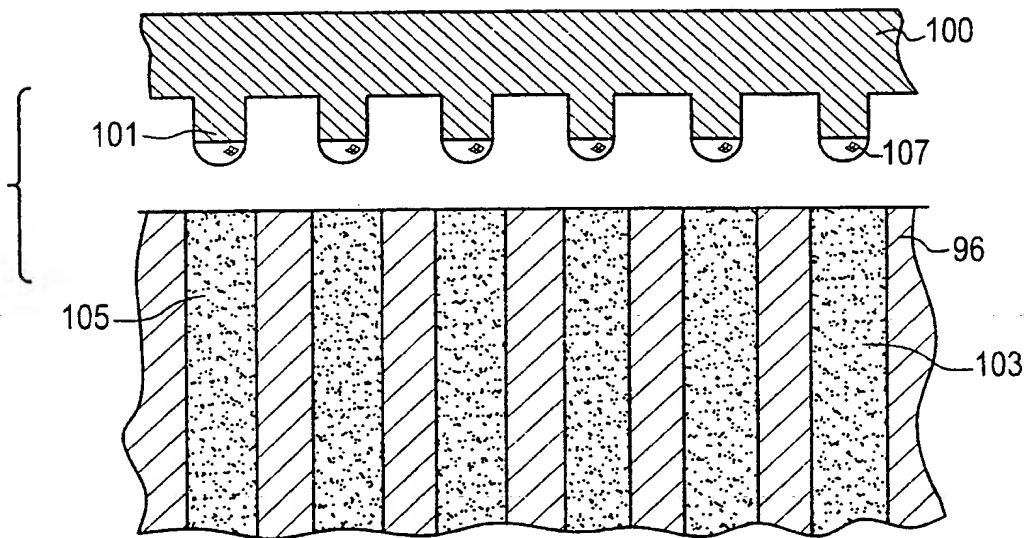
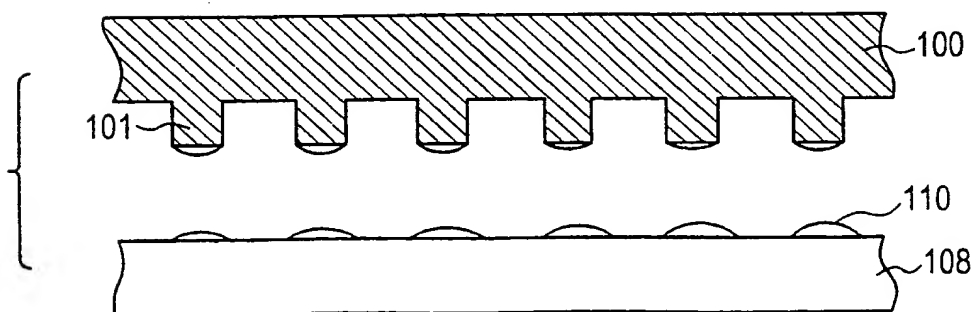


FIG.18



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FIG.19

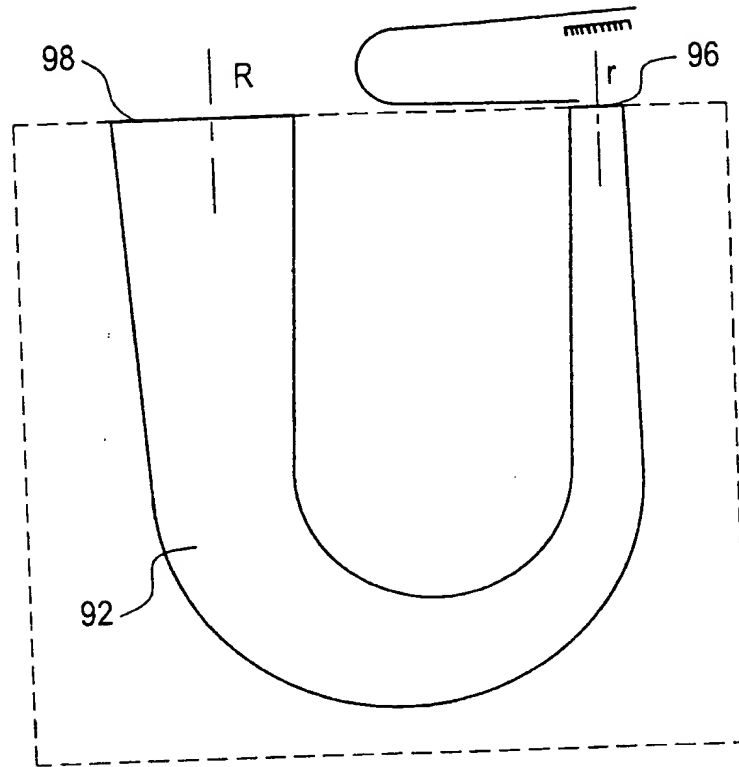
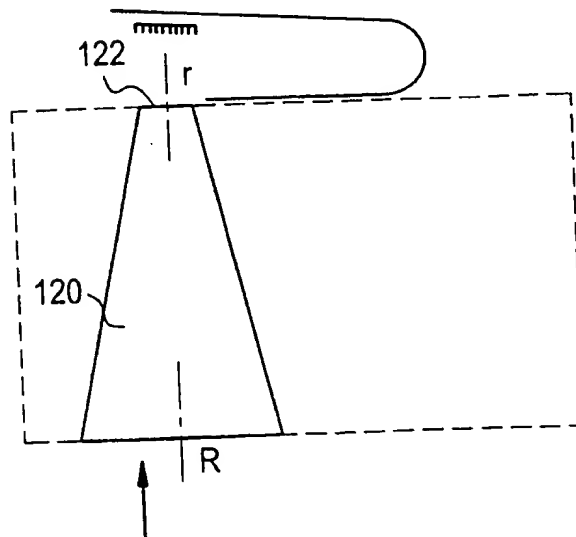


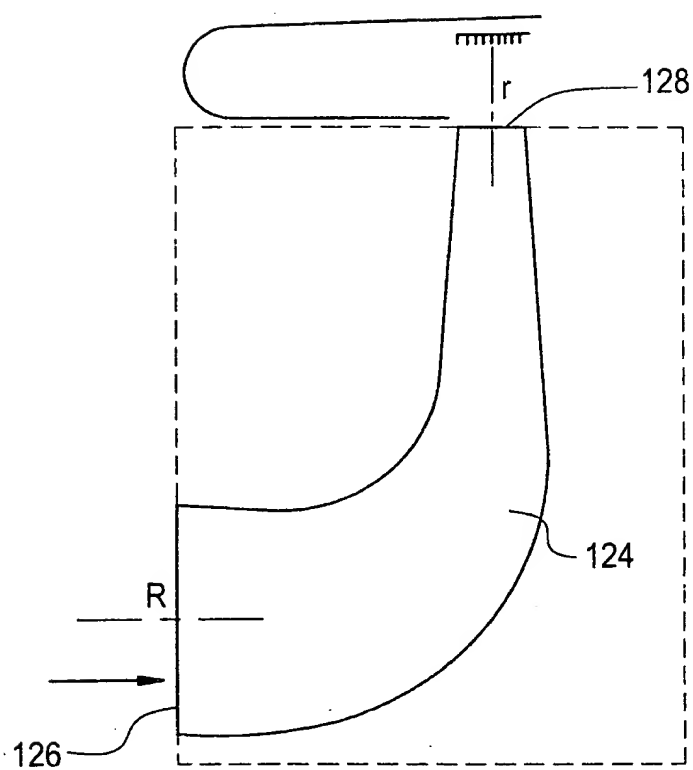
FIG.20



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11 / 12

FIG.21



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12 / 12

FIG.22

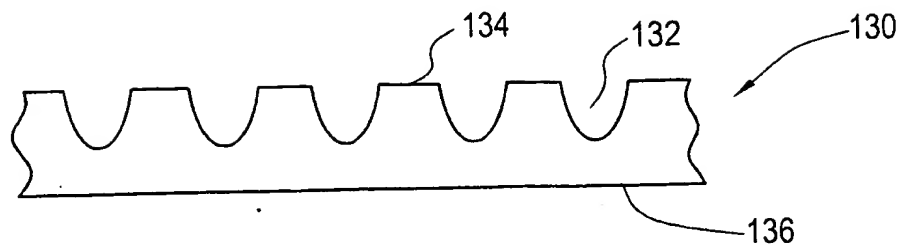


FIG.23

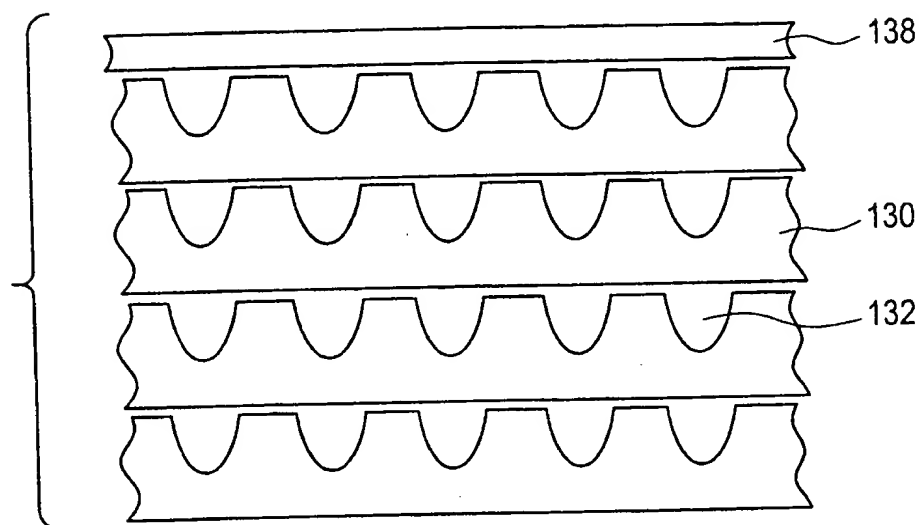
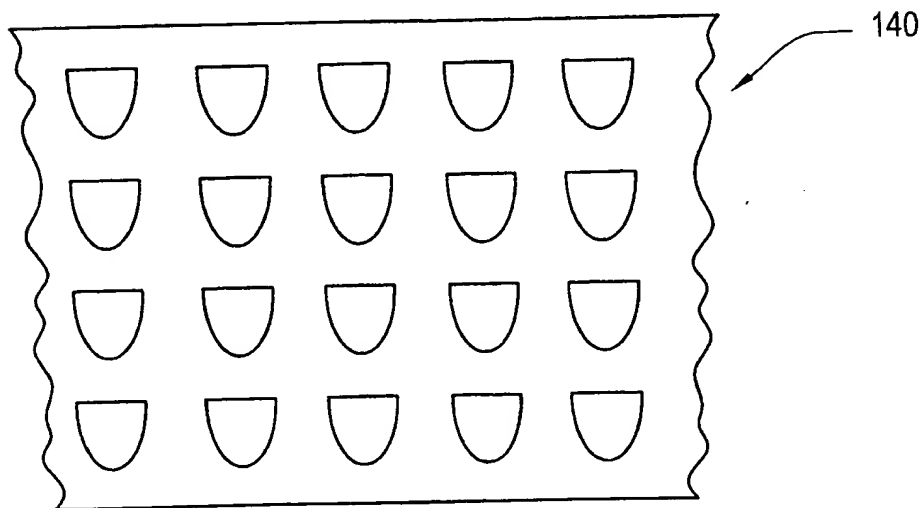


FIG.24



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## INTERNATIONAL SEARCH REPORT

 International application No.  
 PCT/US99/07844

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B01L 3/02

US CL :Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 436/174, 176, 180, 523, 527, 530, 531, 533, 534; 422/100; 65/393, 435, 439, 475; 427/2.13

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS search terms: (print? or jet?) and polymeriz? and acrylamide#; microtome? or slic?; extru? and honeycomb and (draw### or redraw?)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 5,632,957 A (HELLER ET AL) 27 May 1997 (27.05.97), Figure 17, column 15, lines 56-67 and column 16, lines 12-15.	1-12, 36 ----- 34
X	US 4,621,655 A (WEBB) 11 November 1986 (11.11.86), Figures 1 and 4.	9-12
Y	US 4,216,245 A (JOHNSON) 05 August 1980 (05.08.80), column 3, lines 6-12.	13-16
X -- Y	US 5,637,126 A (EMA ET AL) 10 June 1997 (10.06.97), Figure 2.	1-6, 43 ----- 13-16
X -- Y	US 5,678,165 A (WU) 14 October 1997 (14.10.97), column 4, lines 35-37 and column 5, lines 60-62.	17-20 ----- 34



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A* document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
*B* earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*A* document member of the same patent family
*O* document referring to an oral disclosure, use, exhibition or other means	
*P* document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

13 JULY 1999

Date of mailing of the international search report

28 JUL 1999

 Name and mailing address of the ISA/US  
 Commissioner of Patents and Trademarks  
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Authorized officer

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Telephone No. (703) 308-0661

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/07844

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,914,022 A (FURMANSKI ET AL) 03 April 1990 (03.04.90), column 3, lines 10-16 and column 6, lines 1-5.	21-33
X	US 5,585,275 A (HUDSON ET AL) 17 December 1996 (17.12.96), Figure 2a and column 15, lines 55-67.	35, 38, 39, 41
X	US 5,188,733 A (WANG ET AL) 23 February 1993 (23.02.93), Figure 2, column 4, lines 20-43 and 56-57, and column 6, lines 29-30.	36, 37, 39, 41-42
X, P	US 5,843,767 A (BEATTIE) 01 December 1998 (01.12.98), Figure 1A, column 5, lines 28-48 and column 6, line 6.	36, 39-41



# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/07844

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

# INTERNATIONAL SEARCH REPORT

International application No.

\*PCT/US99/07844

## A. CLASSIFICATION OF SUBJECT MATTER:

US CL :

436/174, 176, 180, 523, 527, 530, 531, 533, 534; 422/100; 65/393, 435, 439, 475; 427/2.13

## BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING

This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I, claim(s) 1-34, 43, drawn to a tool, method of use and method of making, wherein the tool is an array of channels having inlets larger than the outlets.

Group II, claim(s) 35, drawn to an array of binding entity beads on a substrate.

Group III, claim(s) 36, drawn to a channel block with binding entities in the channel(s).

Group IV, claims 37, 42, drawn to a sheet having a lattice network containing binding entities.

Group V, claim 38, drawn to a polymer matrix bound to a substrate and containing samples.

Group VI, claims 39-41, drawn to an array of wells containing binding entities.

The inventions listed as Groups I-VI do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: Each group has a different special technical feature as explained above in describing the different groups.